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14. ABSTRACT

A wireless energy transfer system is developed for recharging a Soldier worn battery and batteries of Soldier worn devices. The system is integrated into a Stryker vehicle seat and the Soldiers tactical vest.

15. SUBJECT TERMS

'Wireless Power', 'Wireless Recharging'

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Final Report

Transparent War Fighter Recharging

Contract Number

W15P7T-13-C-A903

Prepared by:

Jeffrey Gibala

Principal Engineer

Powercast Corporation

566 Alpha Drive

Pittsburgh, PA 15238

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1 Summary

The following report details the Transparent Warfighter Recharging system developed under contract W15P7T-13-C-A903. This project had two main objectives;

1. Wirelessly recharge a Li-Ion battery pack, carried on the Soldier's person, from a transmitting coil installed in a Stryker vehicle seat. The target distance and efficiency for the power transfer is 60 Watts over 6 inches at 75% efficiency.

2. Wirelessly transfer power from the Li-Ion battery, carried on the Soldier's person, to some device carried by the Soldier. The target distance and efficiency for the power transfer of this objective is 60 Watts over 2 inches at 75% efficiency.

The developed system described here transferred 60 Watts over 6 inches at 67% efficiency from a 9 inch diameter coil mounted in the Stryker seatback to a receiver, with a 9 inch diameter coil, that can be integrated into the Soldiers vest. And it transferred 50 Watts, using 2.25 inch coils, from the Li-Ion battery pack over 2 inches at 67.55% efficiency to a receiver and attached load. The maximum battery output current of 5 Amps limited the power transferred between the battery and end load to 50 Watts. Without this limitation the design could allow for higher power transfer.

The measured results of the prototype system are presented in Section 6 of this report.

2 System Overview

The Transparent Warfighter Recharging system is an adaptation of an existing patented spread spectrum magnetic coupling technology that was developed for efficiently transferring energy to a high power medical implant. This system is referred to by the acronym 'TETS' which stands for Transcutaneous Energy Transfer System. This acronym appears in certain places of the project documentation and refers to the 'Transparent Warfighter Recharging System'.

The developed system consists of three main components, the Stryker Seat Transmitter, Vest Receiver/Transmitter and End Device receiver.

The Stryker Seat Transmitter consists of a Primary Controller Printed Circuit Board Assembly (PCBA) and a transmitting coil integrated into the seat back. The Primary Controller drives the coil with an AC signal to create a magnetic field around the coil. Based on feedback from the Vest Receiver/Transmitter, the Primary Controller manages the drive signal to the coil and regulates the power delivered to the Vest Receiver/Transmitter.

The Vest Receiver/Transmitter consists of a receiving coil, mounted in the back of the tactical vest, and wired to a PCBA that has receiver and transmitter circuitry. The receiver circuitry rectifies and converts to DC the signal received from the coil and charges a Li-Ion battery pack

that is housed in the vest. The transmitter circuitry is powered by the Li-Ion battery back and drives, with an AC signal, one of four selectable transmitter coils that are mounted in the front of the vest. The coils in the front of the vest generate a magnetic field delivering power to an End Device that is in range. Based on feedback from the End Device the Vest Transmitter manages the drive signal to the coil and regulates the power delivered to the End Device.

The End Device consists of a receiving coil that is wired to a PCBA with circuitry that rectifies the received signal to produce a DC voltage. This DC voltage is available at the End Device output to power an attached load.

Regulation is accomplished by feedback from the system receivers to the respective transmitter, the feedback data is communicated from receiver to transmitter via 915MHz radio links. The system has two 915Mhz radio links, one from Vest Receiver to Stryker Seat and a second from End Device to Vest Transmitter.

The system is powered by 28VDC from the Stryker vehicle.

Below is a system block diagram.

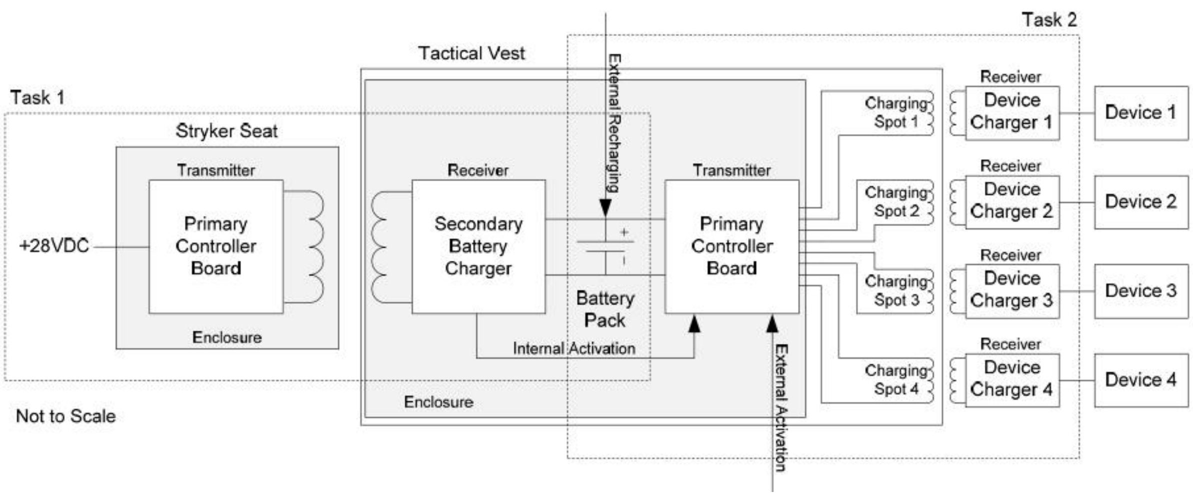

Figure 1- System Block Diagram

3 Theory of Operation

The designed system operates on the principal of magnetic coupling between two inductive coils. In such a system a transmitting coil is driven with an AC current to create a varying magnetic field in the vicinity of the driven coil. A second coil placed in the vicinity of the driven coil will have a voltage induced across it provided that it intersects the flux created by the driven coil. This characteristic is described by Faradays law. The magnitude of the voltage induced on the second coil depends on the percentage of the transmitting coil's flux intersected by the second coil. The ratio of the partial flux enclosed by the second coil to the current in the transmitting

coil is the Mutual inductance between the two coils. The magnetic field of a conductor loop and flux linkage between two coils is shown graphically in Figure 2 and Figure 3.

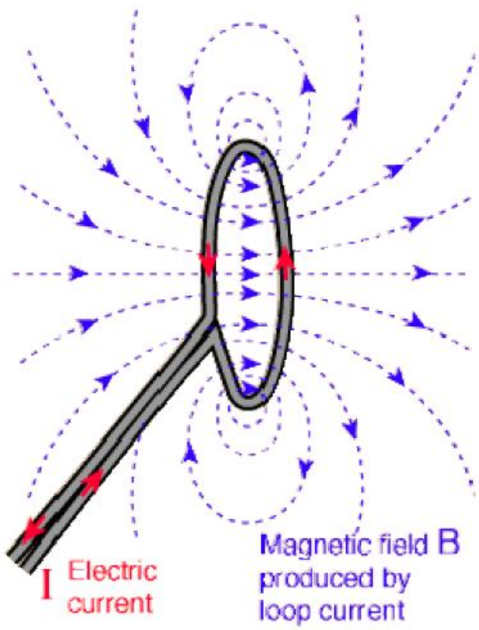

Figure 2- Magnetic field of conductor loop [1]

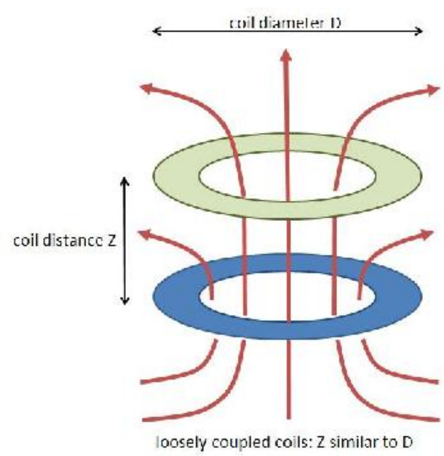

Figure 3- Flux linkage between two coils [2]

$$M12 = \frac{B_2(I_1) * N_2 * A_2}{I_1}$$

Equation 1 - Mutual inductance between two coils [3]

Mutual inductance is a quantitative description of the flux coupling of two conductor loops. The coupling coefficient k is a qualitative figure of merit about the coupling between two conductor loops.[3] The coupling coefficient is given by Equation 2. The value of k can vary between 0, no coupling, and 1, complete coupling where both coils would have the same magnetic flux. A system with a coupling factor of 1 can transfer high power at very high efficiency, a conventional transformer is an example of a system with a coupling factor close to 1.

$$k = \frac{M}{\sqrt{L_1 * L_2}}$$

Equation 2- Coupling Coefficient

Because of coil size constraints and desired energy transfer distances the Coupling Coefficient between the coils of the Transparent Warfighter Recharging system is inherently low. To overcome this low coupling factor the system operates in resonance, meaning the transmitter and receiver coils are tuned with capacitors to resonate at the same frequency as the drive signal. A simplified schematic of this configuration is shown in Figure 4. The resonant frequency of such a circuit is given by Equation 3.

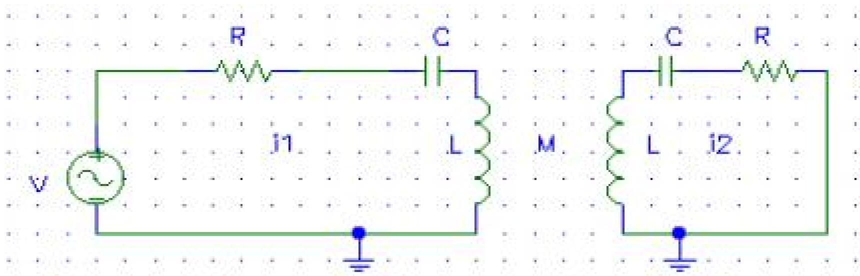

Figure 4- Schematic- Coupled Resonant Circuits [5]

$$f = \frac{1}{2\pi\sqrt{LC}}$$

Equation 3- Resonant Frequency of LC Circuit

When the resonant circuit is driven at the resonant frequency the energy added to the circuit will transfer back and forth between the magnetic field of the inductor and the electric field of the capacitor. On each cycle of the resonance some energy will be stored, some will be transferred to the second coil, some will be lost to resistive elements of the circuits and some will be loss to radiation. To have high transfer efficiency with a low coupling factor the amount of energy stored by the resonant circuit should be high and the amount lost should be low. The radiation losses will be low since the diameter of the coils is small compared to the wavelength of the resonant frequency. To keep the other losses low the circuit Q must be high.

Q is a figure of merit for a resonant circuit and is related to the ratio of the energy stored to the energy lost in each cycle. If the amount of energy lost during each cycle is much lower than the energy stored then power transfer can be done efficiently between coupled resonant circuits that have a low coupling factor.

$$Q = 2\pi \times \frac{\text{Energy Stored}}{\text{Energy dissipated per cycle}} = 2\pi f_r \times \frac{\text{Energy Stored}}{\text{Power Loss}}.$$

Figure 5- Q Relationship to Circuit Energy[31]

The relationship of circuit Q to circuit L,C and R is shown in Equation 4. Q is also related to the bandwidth of the tuned circuit. Equation 5 shows the relationship of circuit Q to circuit bandwidth, where f_0 is the resonant frequency and f_{3dB} is the 3dB bandwidth.

$$Q = \frac{1}{R}\sqrt{\frac{L}{C}}$$

Equation 4- Q Relationship to Circuit L, C and R

$$Q = f_0/f_{3dB}$$

Equation 5- Q Relationship to Circuit Bandwidth

It should be intuitive from Equation 4 that to maximize circuit Q the circuit L/C ratio should be high and the circuit R should be low. It should also be intuitive from Equation 5 that a high Q circuit is narrow band. Care must be taken in the selection of circuit Q, if too high, the resonant inductive system can become unstable and suffer efficiency drops and lowered power transfer due to detuning caused by component self heating, component aging and environmental factors. A tradeoff between system performance and stability must be made.

In addition to circuit design environmental factors also play a role in the circuit Q. Any conductive materials; metal, carbon fiber, etc. that are nearby and intersect the magnetic field will have Eddy currents induced in the material. These Eddy currents will create losses due to the resistance of the material and will also counteract the transmitted field reducing its strength. If conductive materials are in the vicinity of the system's magnetic fields low loss shielding must be used to maintain system efficiencies.

Typical, narrow-band magnetic inductive power transmission generates significant electromagnetic interference (EMI). This results in failure to meet regulatory requirements such as FCC and a large RF signature for the device. The developed system mitigates the problems associated with electromagnetic interference by utilizing spread spectrum frequency modulation for power transmission. The spread spectrum modulation used is frequency hopping spread spectrum (FHSS) . In that regard, power is transmitted by a transmitting device via a primary

coil at frequencies varying or spread within a range of frequencies under the control of a spread spectrum algorithm. In this system , the power transmission channel is cycled from approximately 120 kHz to approximately 130 kHz at 1 millisecond (or ms) intervals to achieve a nominal 125 kHz transmission frequency. A graph representation of this can be seen in Figure 6.

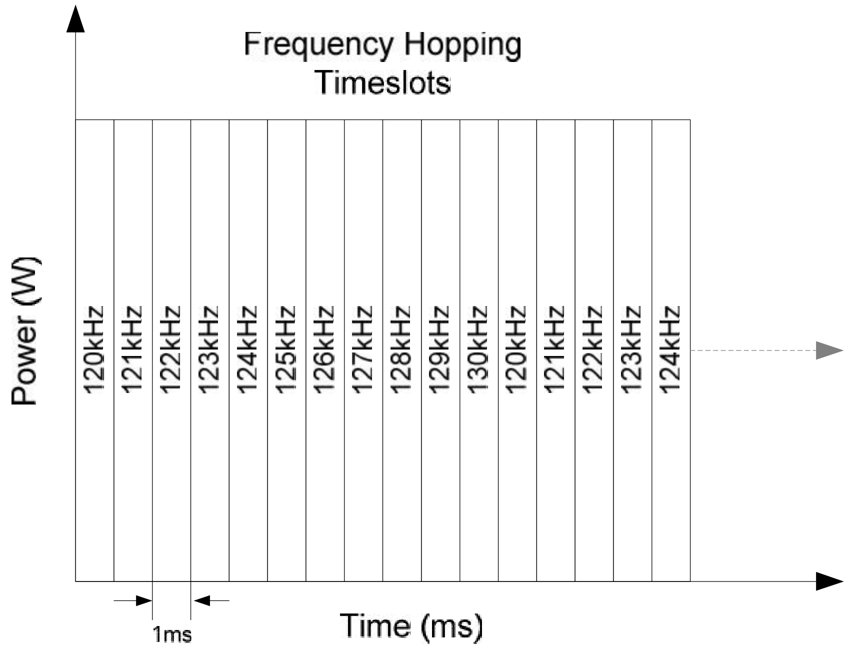

Figure 6- Graphical Representation of Frequency Hopping Magnetic Power Transfer

Use of frequency hopping spread spectrum modulation "spreads" the fundamental and harmonic energy across a number of frequency band channels on a wider electromagnetic spectrum, resulting in decreased narrowband interference and lower average power per channel. This maintains FCC compliance for radiated emissions at a higher power level than a system that operates at a single frequency.

4 Mechanicals

The seatback consists of a PVC clamshell that mates together and encapsulates the transmitting coil and a ferrite shield. An enclosure that houses the transmitter PCBA is attached to the back side of the PVC seatback.

The transmitting coil measures 9 inches in diameter. The main driver in using this diameter coil was to achieve high efficiency over a 6 inch distance. Many power transfer and efficiency tests were done using different size coils and that data was presented in the monthly progress reports. Based on this testing the 9 inch coil size was chosen.

An analysis of the coil size versus soldier body size was performed and it shows that the 9 inch coil fits on the back of the 95th% male and the 5th % female soldier. Figure 7 shows the coil, represented by the blue square, mounted on the soldier’s back.

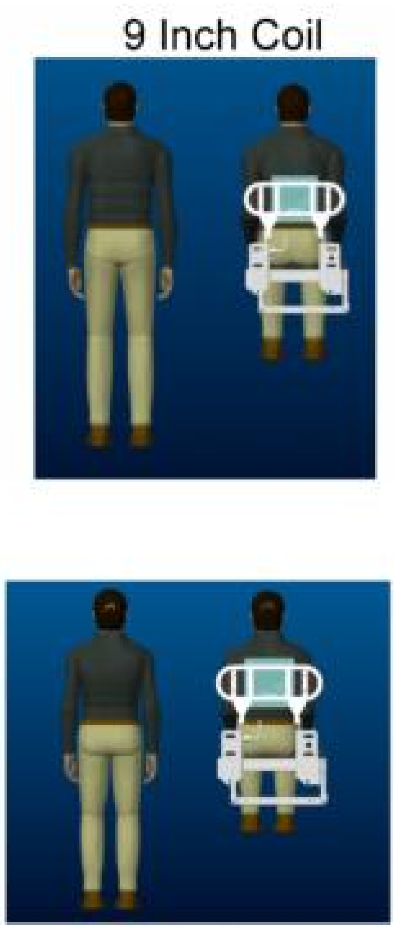

Figure 7- 9 inch Coil on Soldier, above 95% male, below 5% female

The ferrite shielding material was fabricated to a custom shape to match the frame of the seatback. This material provides excellent shielding from the seat frame. Efficiency without the shielding was on the order of 10% and with the shielding efficiencies as high as 78% were achieved.

5 Test Set Ups

The following describes the test setups used to measure system performance.

5.1 Test Set Up Stryker Seat

Figure 8 shows the test set up used to measure the power transfer distance and efficiency from the seatback to Soldier electronics. The receiver coil was mounted to a non-metallic fixture such that it was axially aligned with the transmitting coil embedded in the seat back.

Figure 8- Stryker Seat Test Set Up

An electronic load was attached to the rectifier of the Soldier electronics module and programmed to pull the maximum current that could be provided by the transmitter without exceeding 60 Watts into the electronic load.

Transfer distances were measured referenced from the embedded coil to the nearest point of the receive coil.

A 28VDC power supply was used to power the transmitter. Input current was read from the meter on the 28VDC power supply and input voltage was measured at the Transmitter PCBA using a volt meter.   The voltage and current delivered to the load were recorded directly from the electronic load read out.

5.2 Test Set Up Vest Transmitter

The non-integrated Soldier side electronics pack, shown in Figure 21, and the End Device, shown in Figure 25, were used to measure the performance of the Vest Transmitter. The transmitter and receiver coils were placed on a non-metallic surface and separated by a non-metallic spacer.

The output of the End Device was loaded by 2.5 ohms of resistance in series with an electronic load. The electronic load was programmed to pull the maximum load current that could be pulled from the End Device. The voltage across the series combination of the load resistors and electronic load was measured using a volt meter and recorded. The load current was read from the meter on the electronic load and recorded.

The setup was powered from the Li-Ion battery back. The input current was measured using a current probe and the input voltage was measured at a test point on the PCBA using a volt meter.

6 Performance Data

The following graphs show the performance data of the system.

6.1 Stryker Seat Transmitter Performance Measurements

This data presented in Figure 9 and Figure 10was taken by loading the rectified DC voltage in Soldier's electronics pack. It does not include the efficiency of the battery charger.

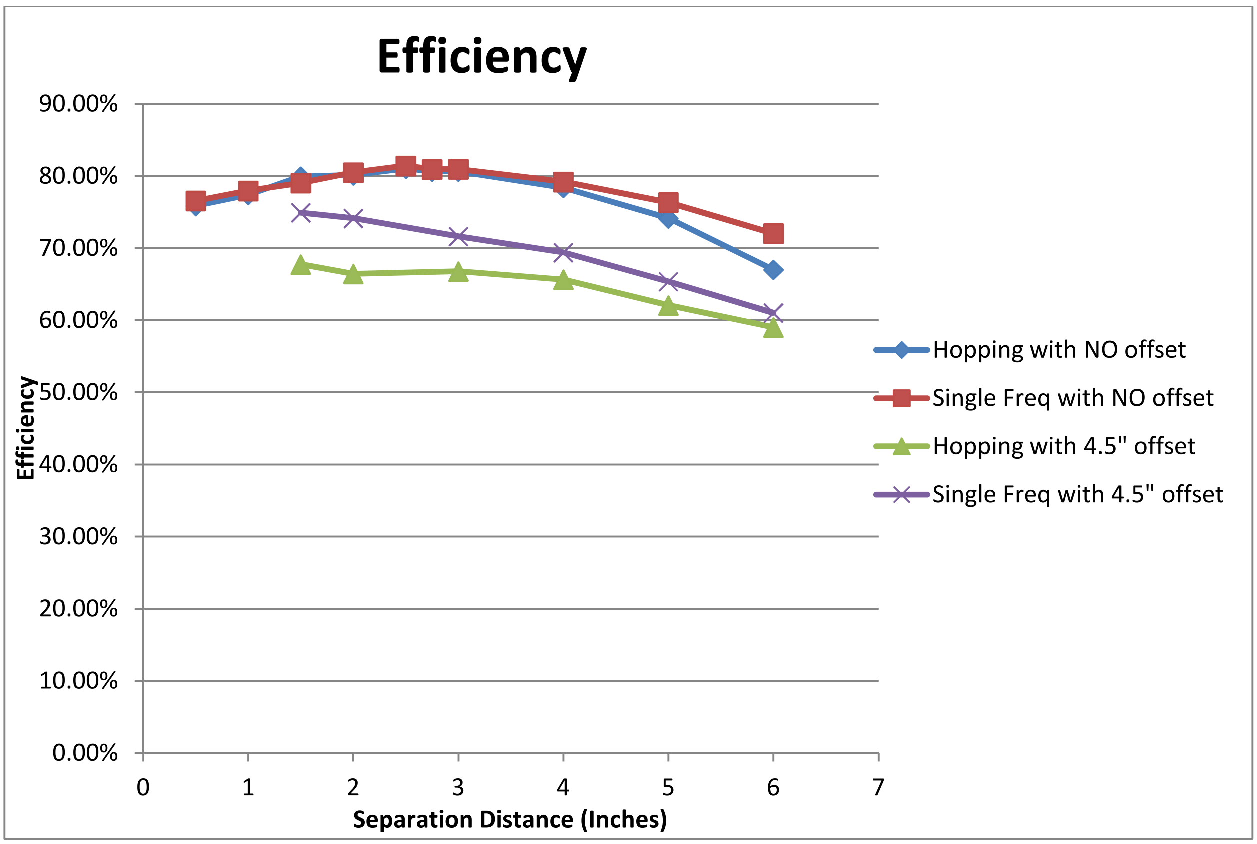

Figure 9- Efficiency vs. Separation Distance Seatback to Vest

Following is an explanation of the different series graphed in Figure 9 and Figure 10.

Hopping with No Offset- Frequency Hopping Enabled Coils Optimally Aligned

Single Freq with No Offset- Transmitter fixed at 125Khz Coils Optimally Aligned

Hopping with 4.5” Offset- Frequency Hopping Enabled Coils Offset laterally by one radius (4.5”)

Single Freq with 4.5” Offset- Transmitter fixed at 125Khz Coils Offset laterally by one radius (4.5”)

Figure 10- Power Transferred vs. Separation Distance

Figure 11 details the charge characteristics of the system charging the Li-Ion battery back over a 6 inch distance with optimally aligned coils.

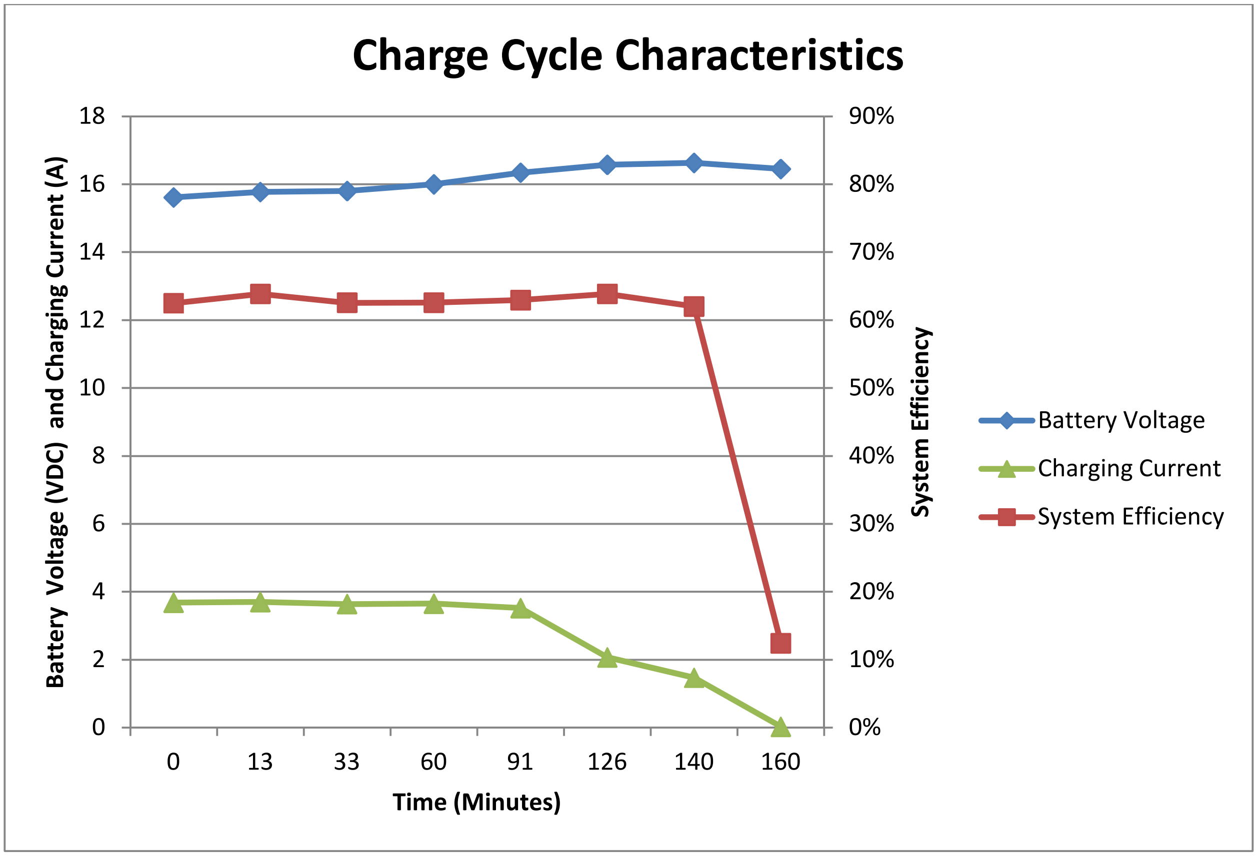

Figure 11- Battery Charge Cycle Characteristics

6.2 Vest Transmitter Performance Measurements

Figure 12 and Figure 13 show the measured power transfer and efficiency from the Vest Transmitter to the End Device. The data sets labeled as 'No Offset' are optimally aligned, data sets labeled as '1.125" offset' have a 1.125 inch lateral offset between transmit and receive coils.

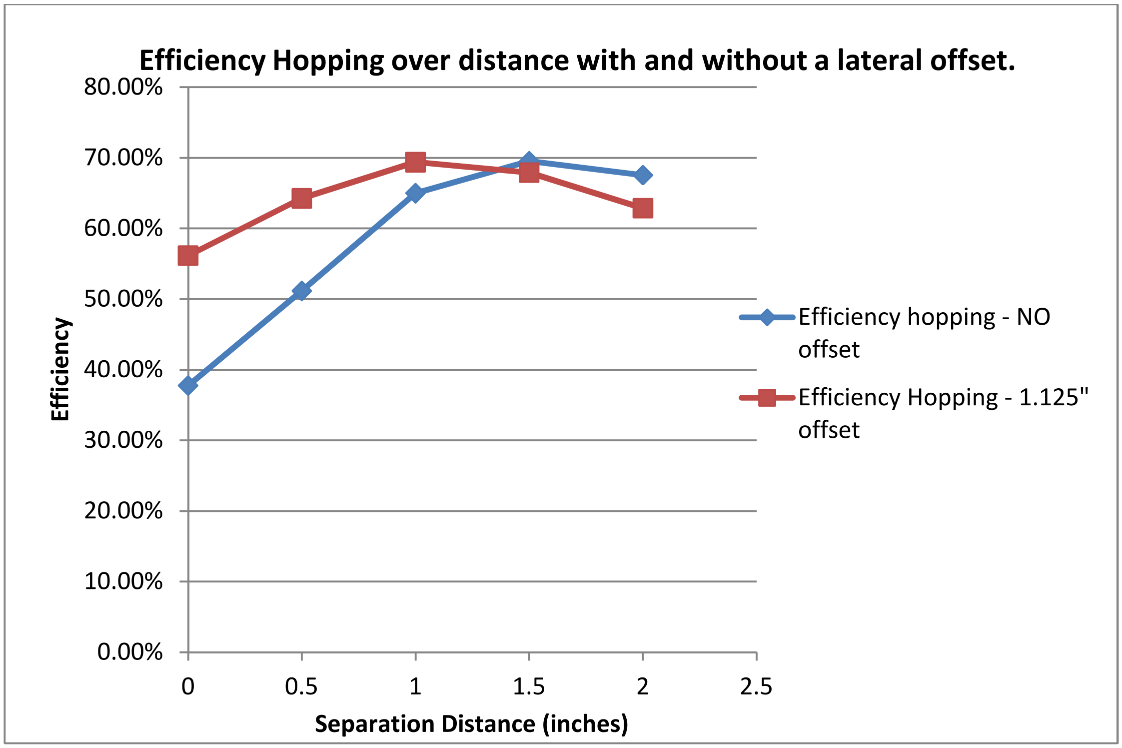

Figure 12- Vest Transmitter to End Device Efficiency

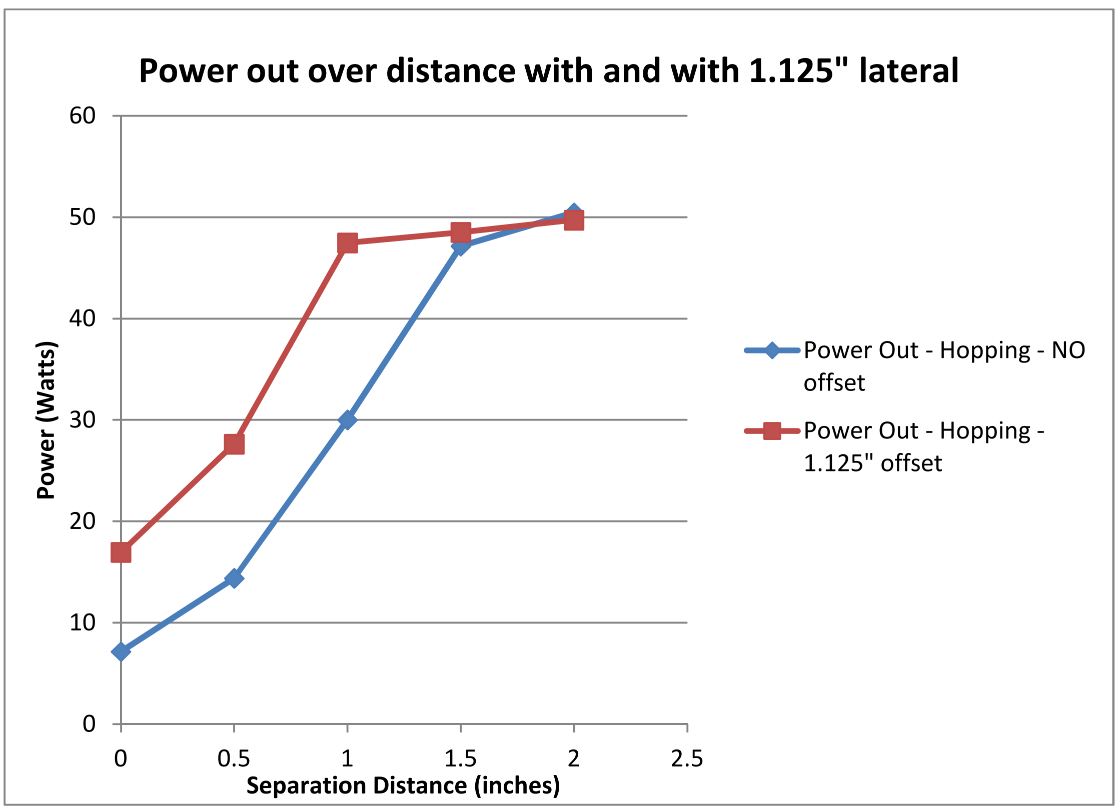

Figure 13- Vest Transmitter to End Device Power Transfer

6.3 System Coil Data

Coil Designator	Diameter Inches	Wire Gauge	Total Turns	Layers of Turns	Measured Inductance uH	Measured Q	Test Freq KHz	Comments
12	9	10	6	2	17.54	210	150	Seatback Integrated System
38	9	10	6	2	17.55	190	150	Seatback Non-Integrated System
43	9	14	6	2	19.51	120	150	For one of the vest coils.
11	9	14	6	2	19.31	140	150	Vest Receive Coil Non-Integrated System
39	2.25	16	12	2	14.65	125	150	For position #1 in vest 31" leads
40	2.25	16	12	2	14.68	130	150	For position #2 in vest 30.5" leads
41	2.25	16	12	2	14.46	140	150	For position #3 in vest 21" leads
42	2.25	16	12	2	14.58	140	150	For position #4 in vest 22" leads
44	2.25	16	12	2	14.33	160	150	End device
45	2.25	16	12	2	14.37	160	150	End device
46	2.25	16	12	2	14.63	130	150	For position #1 of non-integrated system.
47	2.25	16	12	2	14.44	150	150	For position # 3 of non-integrated system.
48	2.25	16	12	2	14.58	130	150	For position #2 of non-integrated system.
49	2.25	16	12	2	14.48	150	150	for position #4 of non-integrated system.

Table 1- System Coil Data

6.4 Signal Waveforms

The following figures show measured waveforms for the seatback and soldier coils. The current waveforms of the following are scaled by a factor of 2.17. They must be multiplied by this value for actual levels.

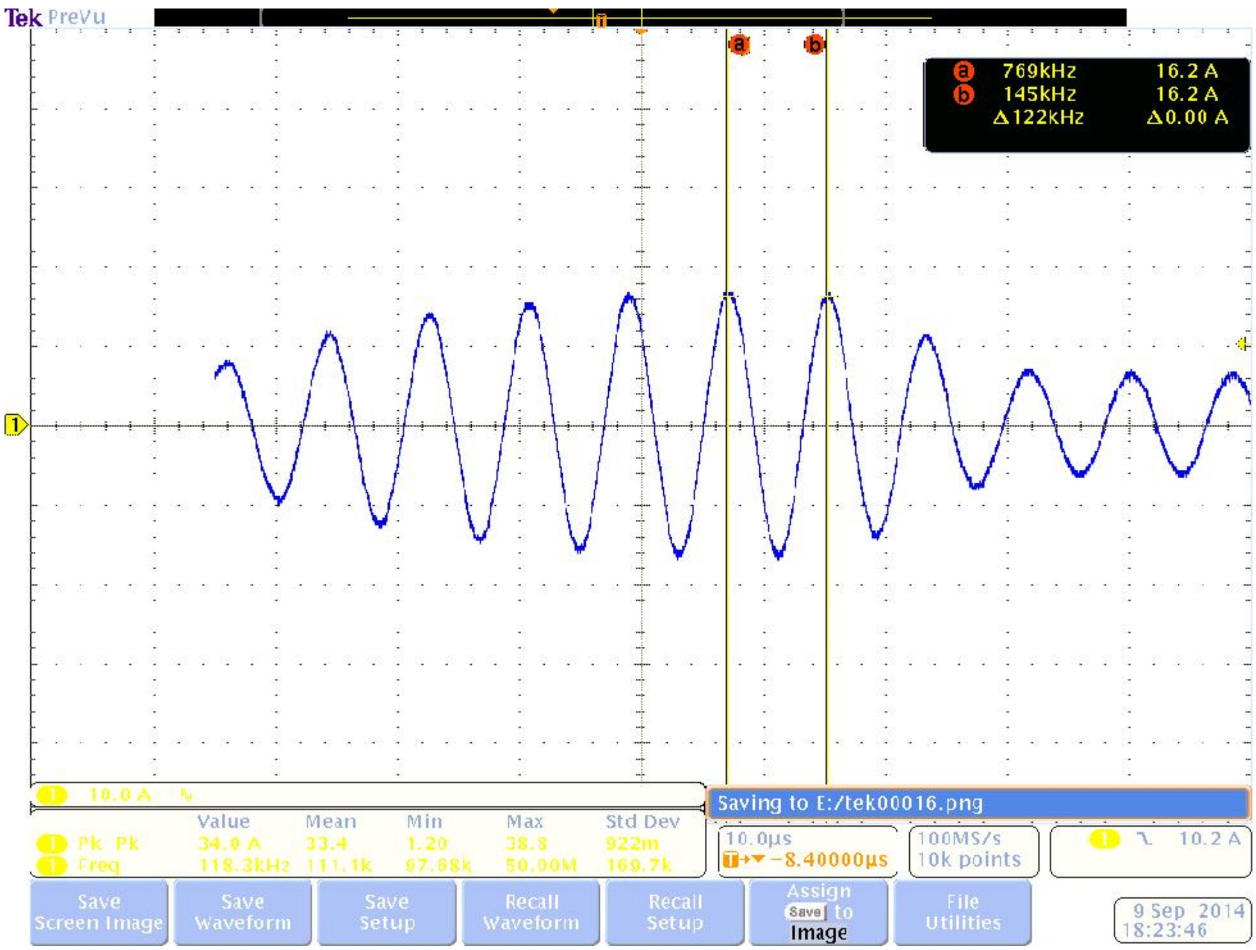

Figure 14- Seatback Transmitter Coil Current

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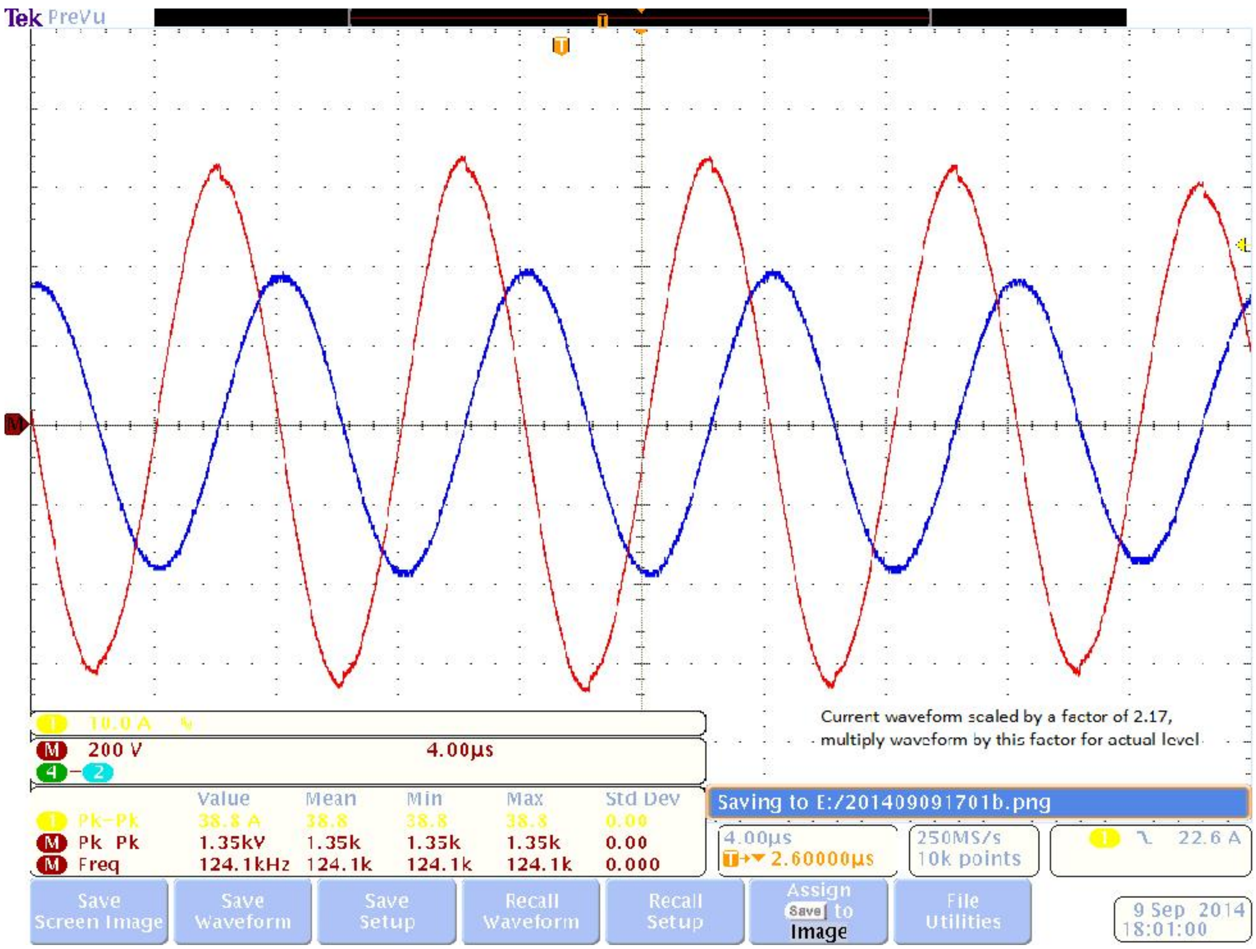

Figure 15- Soldier Receiver Coil Current and Voltage

6.5 Prototype System Assessment

The following tables assess the prototype system characteristics to those given in the proposal.

Task 1

Parameter	**Threshold**	**Objective**	**Proposal Assessment**	**Prototype Measured Performance**
Power Transfer	25W	50W	60W	60W
Range of Transfer	12in*	6in	6in	6 in
Transfer Efficiency	50%	75%	75%	67% DC-in to DC-out 60W @ 6in
Frequency of Transfer	--	--	125 kHz	125 kHz Center frequency of spread spectrum system
Supply Voltage	--	28V	28V	28V

Transmit Coil Size	--	--	12” x 6” x 0.25”	9” inside diameter x 0.45”. Supporting electronics enclosure 6” x 3” x 1.25”
Receive Coil Size	--	--	8” x 8” x 0.25”	9” inside diameter x 0.3”. Supporting electronics enclosure 7.4”x8.5”x1.4”
Transmit Weight	--	--	1.5lb	16.54lbs including seatback *
Receive Weight	--	--	0.5lb	.945 lbs. Excluding battery pack
Compliance		FCC	FCC	Not tested but designed from compliance

*90% of this weight (14.9lbs) is from the ferrite shield and the PVC seatback that encapsulates it. The PVC could be replaced with a lighter weight material.

Table 2- Seat Transmitter/Soldier Receiver Prototype Assessment

Component	Weight in lbs
Tx Coil	.85
Primary Controller	.64375
Seatback	10.5
Power Cable	.14375
Ferrite	4.40
Total	16.54

Table 3- Component Weights Seat Transmitter

Component	Weight in lbs	Comments
Rx Coil	.3125	
Secondary Charger	.2375	
Thermal Pad	.1	
Enclosure	.295	Estimate based on percentage volume of rectifier & charger section
Aux Power Connector	.0375	
Total	.945	

Table 4- Component Weights Soldier Side Receiver

Task 2

Parameter	Threshold	Objective	Proposal Assessment	Prototype Measured Performance
Power Transfer	15W	30W	60W	50W limited by battery pack maximum current
Number of Devices	2	4	4	4

Power per Device	--	--	15W	50W non-simultaneous
Range of Transfer	1in	6in	2in	2 in
Transfer Efficiency	50%	75%	75%	67.5% DC-in to DC-out 50W @ 2in
Frequency of Transfer	--	--	125 kHz	235Khz Center frequency of spread spectrum system
Battery Capacity	--	--	TBD	148 Wh, Palladium Energy Conformal Wearable battery.
Transmit Coil Size	--	--	3-4”	2.25” Inside diameter, supporting electronics enclosure 7.4”x8.5”x1.4”
Receive Coil Size	--	--	2-3”	2.25” Inside diameter
Transmit Weight	--	--	1lb	2.66lbs Excluding battery pack (includes weight of receiver and battery charger)
Receive Weight	--	--	0.1lb	.413 lbs, not including enclosure
Compliance		FCC	FCC	Not tested but designed for compliance

Table 5- Vest Transmitter Prototype Assessment

Component	Weight in lbs	Comments
Primary Controller PCBA	.675	
4 Tx Coils	.7	
Enclosure	1.285	Includes weight of receiver and battery charger
Total	2.66	

Table 6- Component Weights Vest Transmitter

Component	Weight in lbs
Rx Coil	.175
Secondary Charger PCBA	.238
Total	.413

Table 7- Component Weights End Device, Exclude Enclosure

7 RF Emissions

The levels of the system’s intentionally radiated emissions were measured and are provided here as consideration for the ‘No Cost Extension’ that was granted for the contract. Refer to contract amendment P00003 for further details.

The radiated emission levels in the 915 MHz and 125 kHz bands were measured using a spectrum analyzer and appropriate receiving antenna. For 915 MHz the antenna was a half wave length dipole and for 125 kHz a 2.8 inch diameter/12 turn coil measuring 14.37uH was used.

The highest emission measured in the 915 MHz band was the radio carrier at 924 MHz which measured -47.19 dBm at a distance of 66 inches.

This reading is converted to field strength with the following equations.

$$P_w = A_e P^{W}/_{m^2}$$

Equation 6- Received Power relationship to Antenna Area and Power Density

$$P^{W}/_{m^2} = \frac{E^2}{377} \quad \text{where E is in Volts/meter}$$

Equation 7- Relationship to Power Density and Electric Field Strength

$$A_e = \lambda^2 G/4\Pi$$

Equation 8- Effective Area of Antenna

$$\lambda = C/f$$

Equation 9- Wavelength in Free Space

Using the above equations for a signal frequency of 924 MHz measured with a dipole antenna with gain (G) equal to 1.64 the following is obtained.

$\lambda = 3x10^8$m/s / 924 x 10^6/s= .325m

$A_e = .325^2 m^2 * 1.64/4\Pi = .0138m^2$

$P_w = 10^{\frac{-47.19}{10}} = 19.9 \; x \; 10^{-9} \; W$

$P^{W}/_{m^2} = \frac{P_w}{A_e} = 19.1 \; x \; 10^{-9} \; W/.0138m^2 = 1.38 \; x \; 10^{-6} \; W/m^2$

$E = \sqrt{P^{W}/_{m^2}} = \sqrt{1.38 \; x \; 10^{-6} \; W/m^2} = 1177 \frac{uV}{m}$

dBuV/m= 20*log(1177uv/m)= 61.4dBuV/m at 66 inches

A scaling factor of 20 log (66/39.37) or 4.48dB can be applied to scale this reading to a measurement distance of 1 meter. The adjusted level would then be 65.89dBuV/m at 1 meter. This is above the RE102 limit of approximately 44dBuV/m given in Mil spec 461 for ground Army mobile applications. This limit is given as reference and may not be applicable since it is for an unintentional radiator and our system is an intentional radiator. There are no limits given in Mil spec 461 for the fundamental emission of an intentional radiator.

The current through the primary coil was measured while the system was delivering 60 Watts to a load across a 6 inch separation distance. The current waveform is shown in Figure 14 and was

measured to be a maximum of 26A rms. Based on the fact that the coil radius is 0.114 meters (4.5 inches) and has 6 turns the field strength in Amps/Meter can be calculated using equation

$$H = \frac{I * N * R^2}{2\sqrt{(R^2 + x^2)^3}}$$

Equation 10- Field Strength Relationship to Coil Parameters and Distance from Center [3]

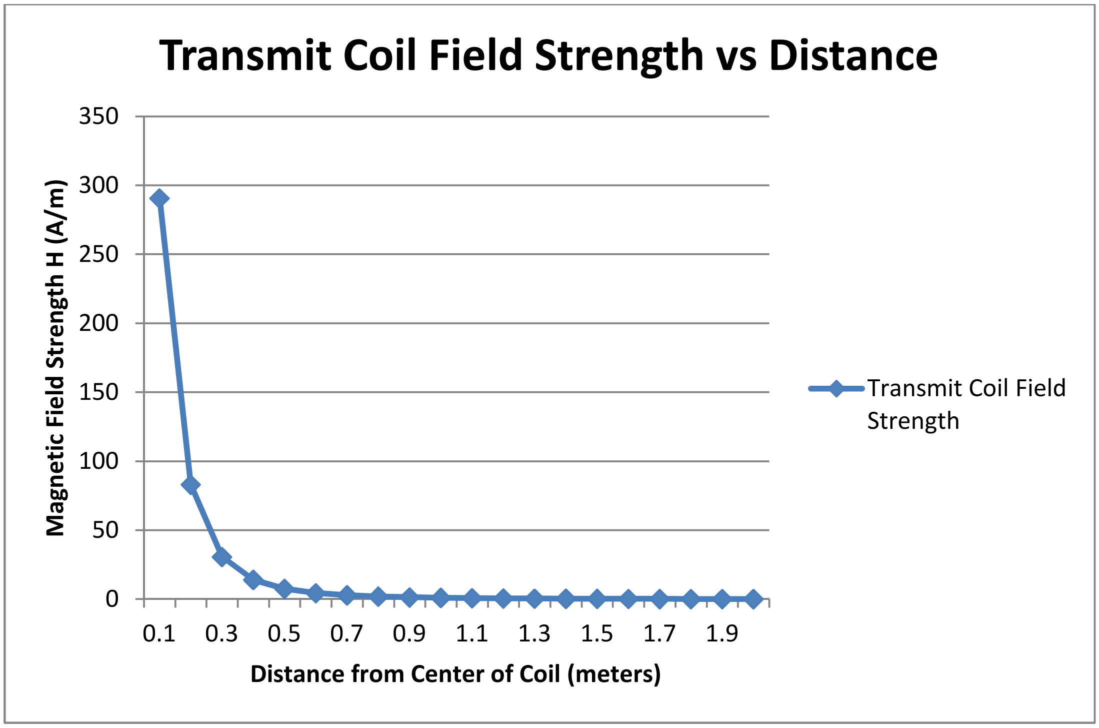

Figure 16- Field Strength vs Distance from Coil Center

H (Amps/Meter)	Offset Distance (meters)
290.6871644	0.1
83.08826076	0.2
30.66717472	0.3
14.08802823	0.4
7.515893033	0.5
4.449877378	0.6
2.841564433	0.7
1.92104936	0.8
1.357712195	0.9
0.994243384	1
0.749491567	1.1
0.57877222	1.2
0.456124987	1.3
0.365775825	1.4
0.297768413	1.5
0.24560977	1.6
0.204943736	1.7
0.172774248	1.8
0.146994987	1.9
0.126095972	2

Table 8- Data Values for Figure 16

A measurement of the field level was taken at 125 kHz using the previously described measurement coil and a spectrum analyzer. A level of -31.69 dBm was measured 1.68 meters from the coil center. This reading is much lower than the theoretical predicted by the graph and is provided as reference only. The scaling factors of the measurement coil used are not known and account for some of the error.

8 System Limitations

The system has two 915 MHz radio links that operate independently. One of the links operates at approximately 906 MHz and is used to communicate data between the seatback transmitter and the receiver in the soldier's vest. The second radio link operates at approximately 924 MHz and it communicates data from the transmitter in the soldier's vest to the end device that is being charged. Both delivered prototype systems use the same radio frequencies for communication

and there is no addressing between devices. Because of this two vest receivers that are near enough to a common seatback transmitter such they both can be powered would interfere. Each of the receivers would send regulation feedback to the transmitter resulting in RF interference and messages to be lost. Secondly, messages received by the transmitter could come from either system which would cause the incorrect regulation on the second system. Because of this the two systems should not be operated within 1000 feet of each other. This limitation can be addressed in the future by using multiple 915 MHz channels that are separated by frequency and through software algorithms that allow the seatback transmitter and soldier receiver to intelligently synchronize and guarantee two systems do not use the same channel.

The seatback transmitter and the Soldier electronics can only be completely powered off by disconnecting the source power. This can be done by unplugging the power cord to the seatback transmitter and unplugging the battery pack from the Soldier electronics PCBA.

9 System Photos

The following figures are photos of the system components.

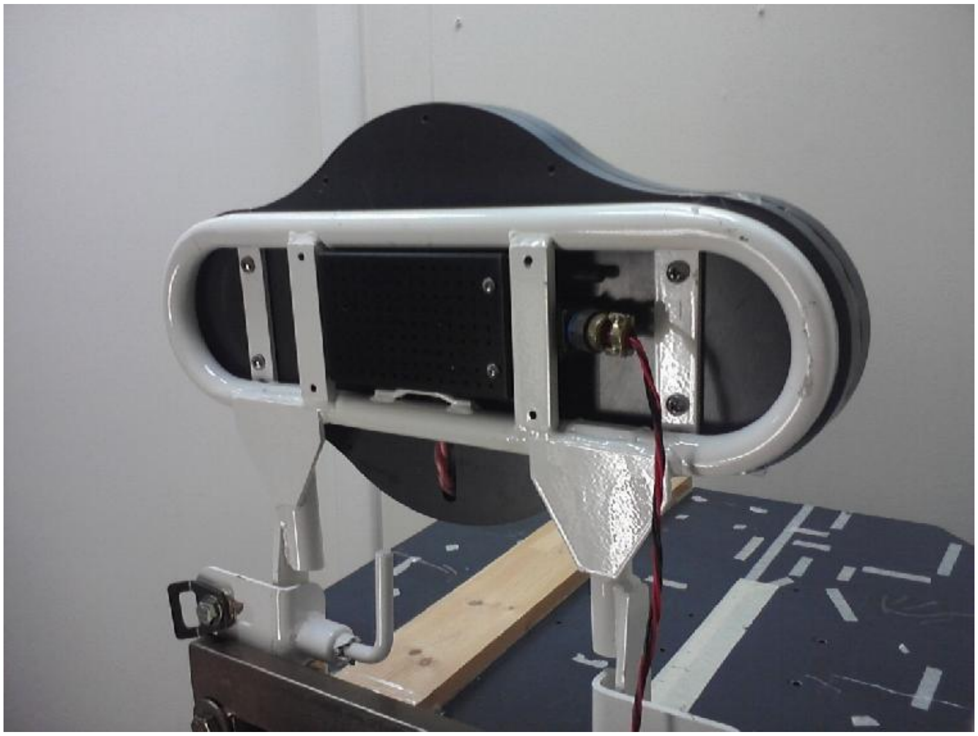

Figure 17- Transmitter and Seatback Installed on Frame

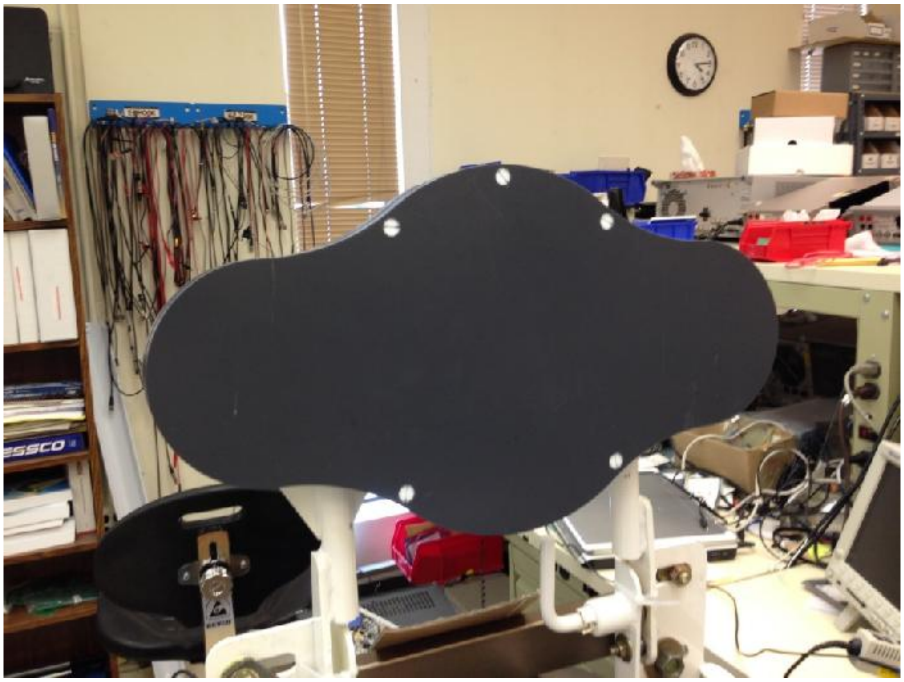

Figure 18- Seatback Front View

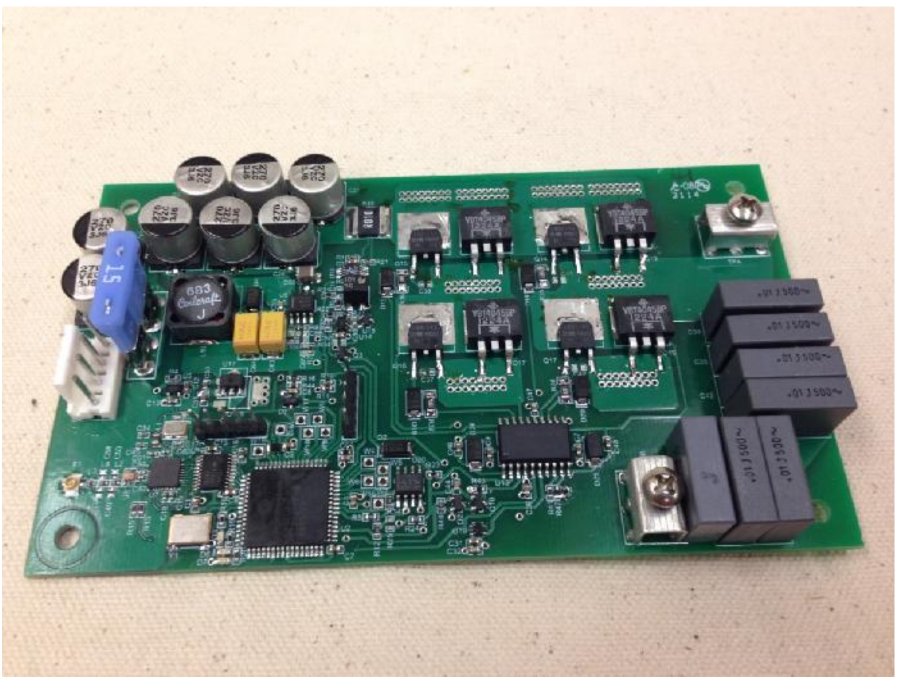

Figure 19- Seatback Transmitter PCBA

Figure 20- Representative Coil Shown on the Outside of Soldier's Vest

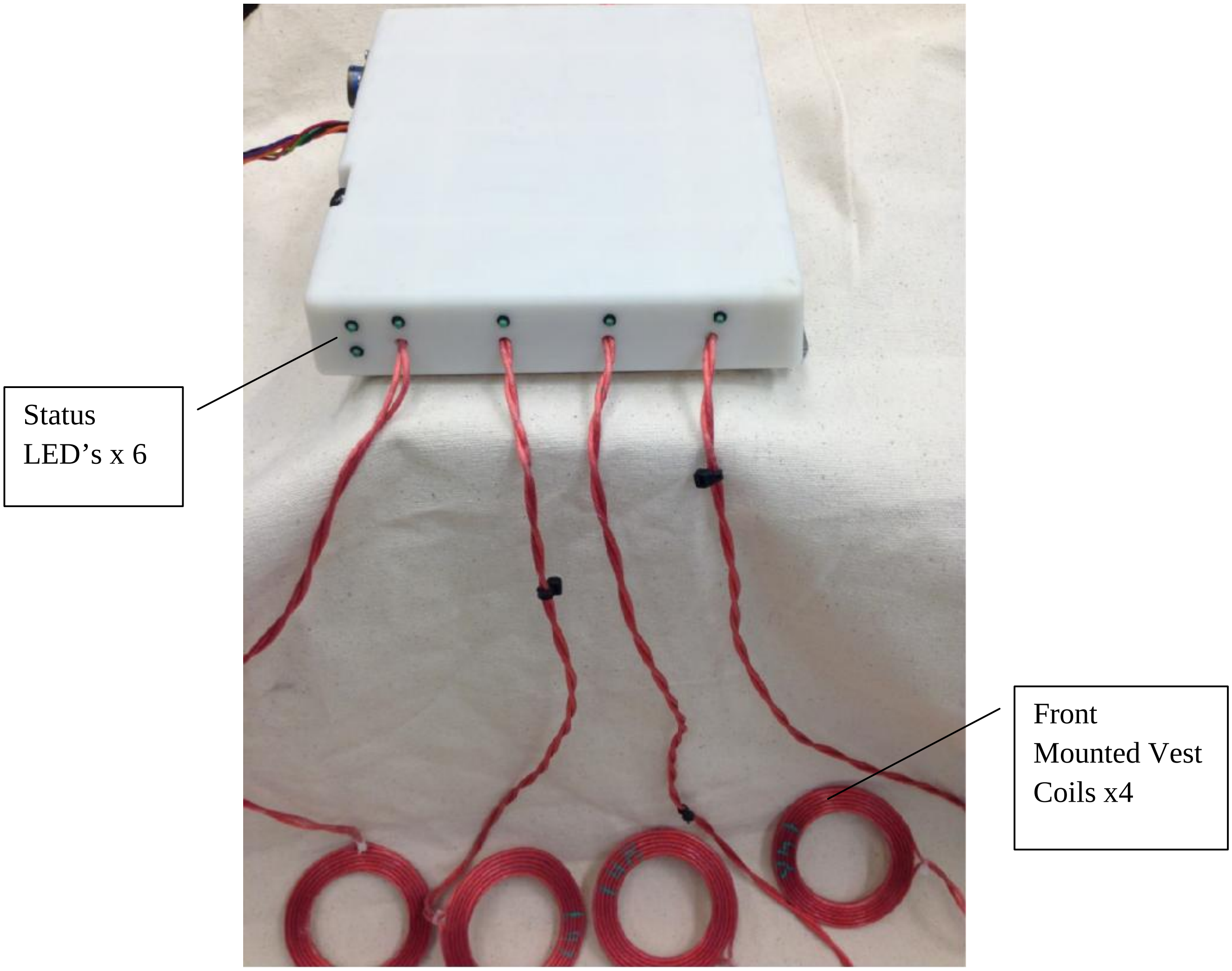

Figure 21- Soldier Vest Electronics- Front View

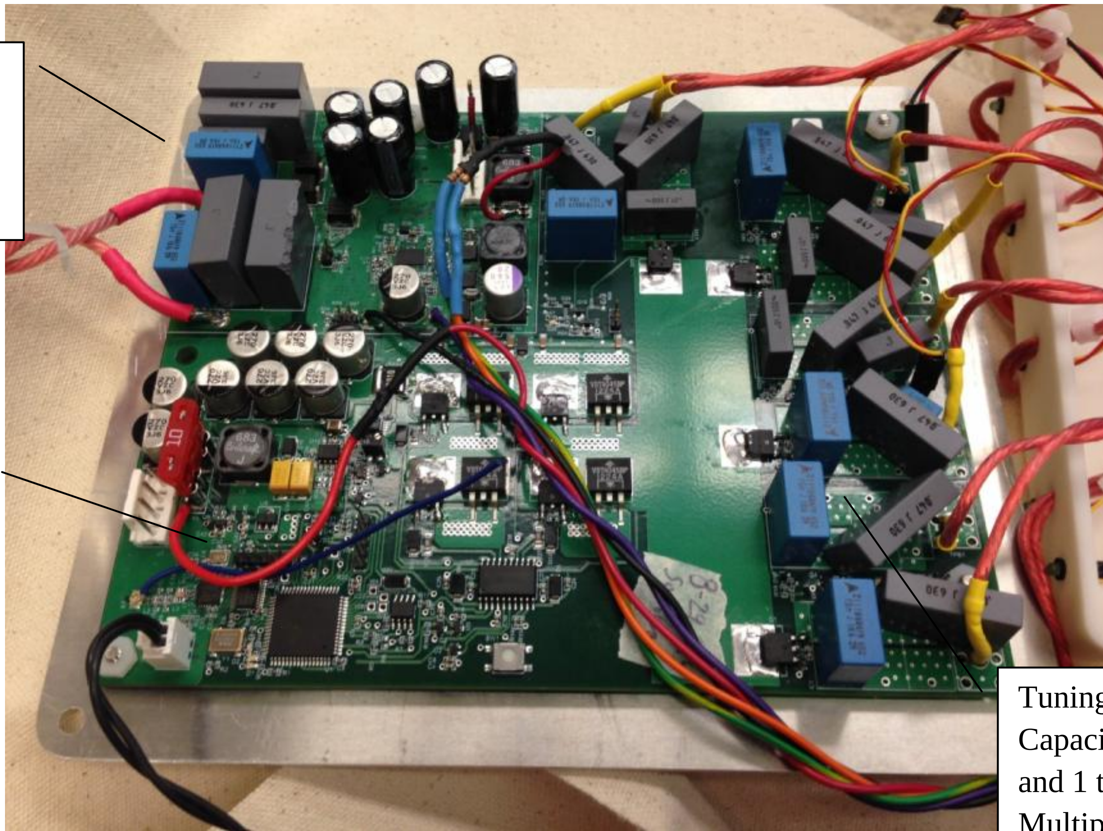

Figure 22- Soldier's Vest Electronics

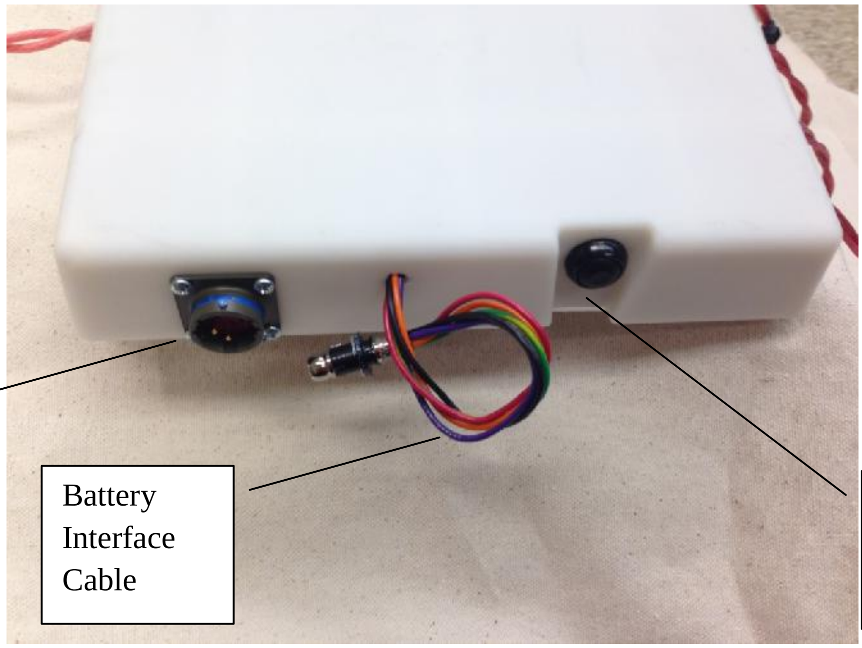

Figure 23- Soldier Vest Electronics- Side View

Figure 24- End Device PCBA

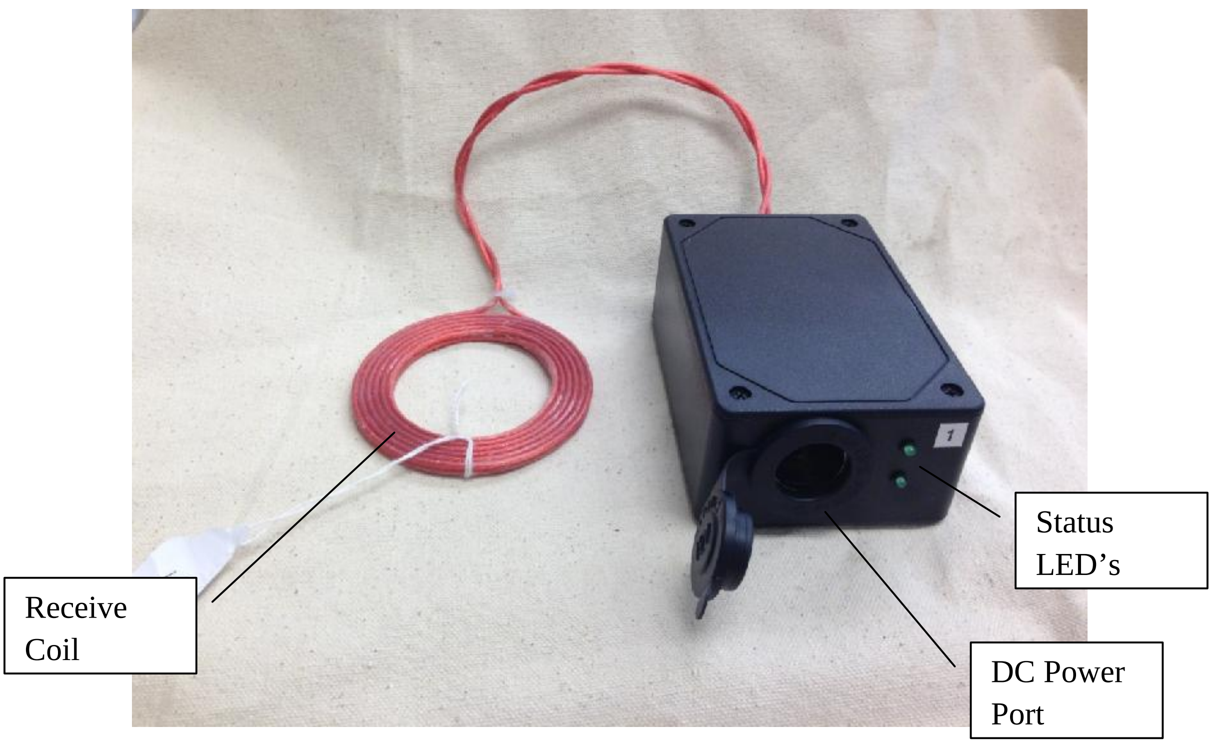

Figure 25- End Device Enclosure

10 Safety

As with any induction system, metal objects will be heated by the generated magnetic field. Testing was performed on a sample piece of metal to gauge the heating affects. Refer to document PCSAR-A2013 titled 'Safety Assessment Report' for all system safety precautions.

The seatback enclosing the coil sets a minimum distance that the metal object can be from the transmitting coil. The areas where the metal object could get the closest to the coil were tested. A steel washer with dimensions of 0.5”x.21”x.054” (Outside Diameter x Inside Diameter x Thickness) was used as the sample.

Location	Item Temperature Degrees C	Temperature Rise Degrees C from Ambient of 22C
Front of seat, nearest inside edge of coil	45	23
Behind Seat nearest inside/outside edge of coil	28.9	6.9
Top Edge Seat, nearest coil	26.6	4.6

Table 9- Heating of Nearby Metal Objects

The measured temperatures are safe to touch at the measured ambient temperature. It is likely the temperature reached varies with material type and geometry so additional testing is recommended. It is recommended that no person that has metal, metal like implants or metal foreign objects such as shrapnel, bullets, etc. use the system and maintain a safe distance from an operating system. Further research and testing should be done to validate the safe use for these instances.

The voltages generated across the system coils are very high, on the order of 425Vrms. Removing the enclosure cover during operation or damaged insulation on the coils presents a shock hazard. Caution must be taken when working on the system.

11 Conclusions

A 28VDC powered system utilizing nine inch diameter resonant inductive coils can transfer 60 Watts over 6 inches at high efficiency and recharge a Li-Ion battery pack. The transmitter can be mounted to a metal seat frame and efficiency maintained with the use of shielding ferrite with the proper characteristics. This system is tolerant to coils offsets of at least one coil radius.

The Li-Ion battery pack can power a system utilizing 2.25" diameter resonant inductive coils to transfer 50W over 2 inches at high efficiency and provide DC power to a device.

Because the power transfer is optimized for a separation distance of 6 inches, for the seatback to Soldier, and 2 inches, from Soldier to End Device, at closer distances the power transferred decreases because of increased coil coupling that results in detuning of the resonant coils. It's possible this could be overcome with intelligent software algorithms that detect and adapt to the increased coupling.

Metal objects near the system coils will experience heating from induced Eddy currents. The amount of heating depends on the geometry of the object and the characteristics (permeability, resistivity, etc) of the specific metal. Further testing is recommended to study the heating effects on nearby metal.

12 References

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